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EXPERIMENTAL INVESTIGATIONS FOR IMPROVING PV MODULE EFFICIENCY USING NANOFLUID

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ABSTRACT

The worldwide growing demand for electrical power, increasing fuel prices and rising concerns about climate change have attracted attention to renewable energies in the last decades. Specially, Jordan severely suffers from sources of energy; which affects its economic level. Even though solar power technologies have progressed a lot in the past years, still low efficiency and high initial cost are the main obstacles for prevalent use of such technologies. A back-surface cooling channel with nanofluid cooling-system is employed in this paper. Cooling channels thickness of, 5cm with two nanofluid (TiO_2) at concentrations (0.05 wt. %, and 0.1 wt. %) volume flow rate of 1L/min, 1.5L/min and 2L/min are used in the experiments. The experiment tests are done in outdoor and performed in Jordan. It is found that during operation, a PV cell in a PV system converts a small portion of the sun light into electrical energy while the remaining converts into loss of heat. In this work, photovoltaic panel use is studied and the results of utilizing nanofluid cooling approach to enhance the system performance are investigated.

Experimental tests are conducted to figure out the best configuration of parameter used for cooling performance of the PV module. The results showed that the cooling channel with thickness of 5 cm, at concentrations (0.1 wt. %) and with volume low rate of 2L/min is the best case for cooling. Without cooling, the operating cell temperature reached the highest value of about (63°C). Using cooling with nanofluid, the reduction was (32.5%). The power of the module without cooling is reached the lowest value of (20.8 W) and with nanofluid cooling it reaches (22.4W) with percentage increase of (7.5%).

KEYWORDS: PV Panel, Efficiency, Water Cooling, Operating Temperature & Indoor Test

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Original Article

1. INTRODUCTION

As known PhotoVoltaic (PV) technology is the solution to many problems such as global warming. One of the main problems in PV systems is overheating, in which rise in surface temperature of PV cell can decrease the efficiency. As a result, PV cooling cells is very important to increase PV cells efficiency.

Many researchers have studied and found various techniques to cool PV systems, so its performance and efficiency will increase. Among these studies, the work carried out by Hossein **Alizadeh et al**. [1], where they used the Pulsating Heat Pipes (PHPs) method which is compact heat transfer devices with high effective thermal performance due to the two-phase heat transfer mechanism. In the results, the electrical power generated is increased by 18% compared without any cooling system. **Shuang-Ying Wu et al.** [2] studied a method to cool a PV module using cooling channel above PV panel and analyzed the influence of mass flow rate, inlet – outlet water temperature and cooling channel height to study how they affect heat transfer characteristics and performance of PV module. They realized that the convection heat transfer at the bottom of PV cell surface is

better than the top of PV cell surface in most cases and this thing associated with Nusselt number. **Linus Idoko et al.** [3] used a multi-concept cooling technique method, this method includes three types of cooling, namely conductive cooling, air passive cooling and water passive cooling. In the results, surface temperature dropped to 20 ◦C, output power increased to 20.96 watts, and the efficiency is increased to not less than 3%. **Soudabeh Golzari et al.** [4] studied the influencing of Corona wind on heat transfer and they realized that the heat transfer coefficient is increased by Corona wind because of vortex and secondary flow made by it. Consequently, the efficiency of PV/T system is increased. Also, they realized that corona wind is effective on enhancing the system performance; so that the heat transfer coefficient increases by 65% and the thermal efficiency of the PV/T system increases up to 28.9%. André F. A et al. [5]. In this paper, they studied the condition which affects the cooling kit system for existing and already working PV plants, they also studied how they can optimize it for a real industrial application and they studied how they can minimize its cost and the amount of water used. This experiment showed how can water cool kit increase the efficiency of PV planet, as it can increase its yearly production of energy up to +12%. Others as in **Siamak Jamali et al**. [6] used the solar chimney system to cool Semi-Transparent PhotoVoltaic (STPV) system. The STPV is to be placed in at the lower part of the solar chimney and an air flow generated by the solar chimney cools the STPV. In the results, the average temperature of the STPV dropped up to 15 °C, and power generation increased up to 29%. Authors as in Usman Jamil Rajput et al. [7] studied the influence of a cylindrical pen fin heat sink and collector on reducing a PV plant temperature. Temperatures declined to 58.4 °C with heat sink and 47.9° using the collector. They realized that the heat flux is enhanced by 30% **-** 40% by the heat sink and PV/T collector by natural methods. **In Fabio Schiroa et al.** [8], while the temperature affects PV cells by reducing its performance, they studied how they can put a water-cooling system to increase cell's efficiency by controlling its temperature, but to keep the cells at its main shape is still under investigation, they used a steady – state methods. **Fatih Selimefendigil et al.** [9]. They studied how porous fins can improve efficiency of PV cells, so, they built a PV module including porous fins and they realized that they can enhance the performance of the PV cells under specific conditions. In **Zeyad A. Haidar et al.** [10] Through gravity, water is supplied to the back of the PV panel from a tank. Evaporation latent heat was used to absorb the generated heat from the body of a PV module to decrease its temperature, Above 20 °C reduction in PV panel temperature and about 14% increase in electrical power generation efficiency. On the other hand, Bruno **Meneghel Zilli et al.** [11] studied the performance and effect of water-cooling on a microgeneration system of photovoltaic solar energy. While increasing PV module's temperature limit performance by increasing the internal resistance and energy losses they studied the influence of water sprinklers system, by locating it underneath module and doing this experiment during three periods of analysis, the first one had intermitting cooling while the second had no cooling and the final one had continuous cooling. These three periods were in the hottest hour of the day. They realized that the efficiency and power are increased by 12.17% and 12.26% respectively in high level of irradiation. Others as in, the efficiency and the power are increased by 9.09% and 8.48%, respectively, in low irradiation level. **Ahmad el Mays et al.** [12]. They used method based on photovoltaic panel cooled by finned aluminum plates and the front temperature was decreased by an average of 6.1 c and an improvement in electrical efficiency by an average of 1.77%. Also, in Qing Yang et al. [13], they used liquid desiccant cooling system (LDCS); the efficiency was increased to 50% when the solution (desiccant) temperature is 20 c. However, **Hatim Machrafi et al.** [14]. Developed a new analytical mathematical model, and he used cooled nanocomposite thermoelectric hybrid system and the overall efficiency shows that a cooling velocity around 10 m/s presents the highest overall efficiency almost 25 %. Theoretically, while **Dengjia Wang et al.** [15] studied an off-grid PV cooling system with TSES combing BS and CWST and investigate the influence of battery efficiency; they used method based on cold water system. In **Aarti Kane et al.** [16], they attached thermoelectric module at the back of the

PV module to absorb the heat, they simulated the results in MATLAB, temperature was reduced at range of (6-26%), and efficiency was improved up to 18% (maximum). Authors in Sanjeev **Jakhar and Manoj S. Soni** [17] made a new cooling system for PV panels named as EWHE, experimentally and theoretically, in their experiment the temperature is decreased from 73C to 52.1C, and the electrical efficiency was improved by range of 8.26–8.52% and the thermal efficiency improved by 44.06–55.45%. **S. S. Chandel and Tanya Agarwal et al.** [18]. Also used Phase Change Material (PCM) as a cooling technique; the efficiency was increased by 5%. Also they found that, using heat sinks and conductivity enhancers with PCM will improve the overall efficiency of the PV panels. In Bachchu Lal Gupta et al. [19] they used a single axis tracking and double axis tracking mechanism techniques, in different claimant zones in India, they realized that the single axis method increased the efficiency up to 10-20%, on the other hand, the double axis method increased the efficiency by 5-15%. **Zhijun Peng et al.** [20]. They studied how can the sun raise up the temperature of the solar panels surfaces, they knew that by doing experiments under different types of radiation and how is the result of current, power, voltage and efficiency variates. Then they studied the influence of cooling condition of solar panels in different places like residence area, they found that the performance is increased by 37% annually and this thing can reduce the payback period. Researchers in **Yiping Wang et al.** [21], studied a new method of cooling dense-array solar cells in high concentrating photovoltaic system by direct-contact liquid film, and water was used as working fluid. The temperature is decreased down to 10oC, and the efficiency is increased up to 44%. **M. Lucas et al**. [22] used evaporative solar chimney as a coolant, the electrical efficiency is enhanced to be at range of (4.9- 7.6%) in summer – Mediterranean climate, and the module temperature is decreased below 30◦C. **Shun Sing Liao et al.** [23] used multi-crystalline silicon solar cells, and they used two steps growth thermal oxide layer to the SiNx passivation layer, this method increased the efficiency by 17.64%. **Mohammad Alobaid et al.** [24]. This review comprises of computational and experimental work focusing on types of collectors, beside their efficiencies and performance indicators. Compared to vapor compression conditioning systems, half of primary energy was conserved by utilizing solar absorption cooling systems while achieving 10–35% maximum electrical efficiency of PVT.

In the present work, a comprehensive heat transfer experimental models are developed in order to simulate the behavior of the PV module with Nano fluid (TiO2) at concentrations (0.05 wt.%, and 0.1 wt.%) cooling system. The temperature through different sections of the system is determined and the performance of the system under channel thicknesses of 5cm and different water flow rates of 1, 1.5 and 2 L/min are presented. The result of the experimental work are presented via several graphs and compared to validate the results. Further, the results obtained which show how the cooling of the system can increase the overall power generation and efficiency of the system.

2. EXPERIMENTAL SETUP

The practical apparatus shown in Figure (1) was constructed on the roof of mechanical engineering department at the Balqa Applied University where three solar cells were placed, one without cooling, the second with water cooling and the third with Nano fluid cooling. All cells were set to work under the same conditions as sunlight, humidity and wind speed.

The direct contact heat exchanger system between the cells and water flow in cooling channel was manufactured, because the intensity of radiations is come from the top. Therefore, the heat exchange was planned to control the temperature of PV module. The experimental setup which is consists of a PV module (poly-crystalline type 30W rated power) and solar thermal collector is shown in Figure (3). The cooling channel (collector) is filled Nano fluid and attached to the back side of the solar panel. The cooling system was operated to solve the overheating problem. The cooling channel

has the same dimensions of the PV module. The Nano fluid flows inside the collector from one side and exits from other side Velocity is higher at the inlet and the outlet. At inlet, it is higher because the flow is coming from the small opening and at the outlet; the flow flows through a small exit. Cooling channel with thickness 5cm and is used and installed on the back side of photovoltaic cells. These channels filled with Nanofluid and water was pumping through the cooling channel with three different volume flow rates of 1L/min, 1.5L/min and 2L/min. All the sides and back surface of the panel were perfectly insulated with silicate. The purpose was to use the maximum thermal energy and minimize the thermal energy losses, and at the same time achieve higher photovoltaic conversion efficiency. One PV panel was provided cooling from bottom, whereas the other sides were kept without cooling. The variable resistance system was utilized to measure Voltage- Current performance of PV module. The solar irradiance measurement device is called pyranometer located at the top of the panels. The temperature of the panels is measured at three locations using thermocouples located at the front of the panels. The output power, solar irradiance, and temperature are all monitored using a data acquisition system. All measurements are saved in an excel file for further calculations and analysis.

The specifications of the PV module used in the test are given in Tables (1). The cooling water comes from tank to channel connected to the PV/T system through plastic pipes of 0.5 inch diameter. A water pump with capacity of (0.5 hp) is used to circulate the water through the cooling system. To regulate water flow rate inside the cooling channel, a flow-meter with maximum volume flow rate of 2 L/min is used. The water water flows through the cooling channel captures the waste heat from the PV module and produce hot water which is collected at the outlet tank. The water temperature is measured using standard type-thermocouples attached at the inlet and outlet Ports of the cooling channel. Cooling flow rate water varied from 1 L/min. to 2 L/min. and the V-I performance of the PV panel was evaluated. The water at outlet was drained out in to open tank and was then recirculated using a DC (Direct Current) pump. The hot water coming from the PV panels is cooled due to heat exchanger pass through the large amount of cold water inside the tank.

Figure 1: Actual Experimental Setup.

A schematic format of the framework PV-cooled structure is outlined in Figure 2.

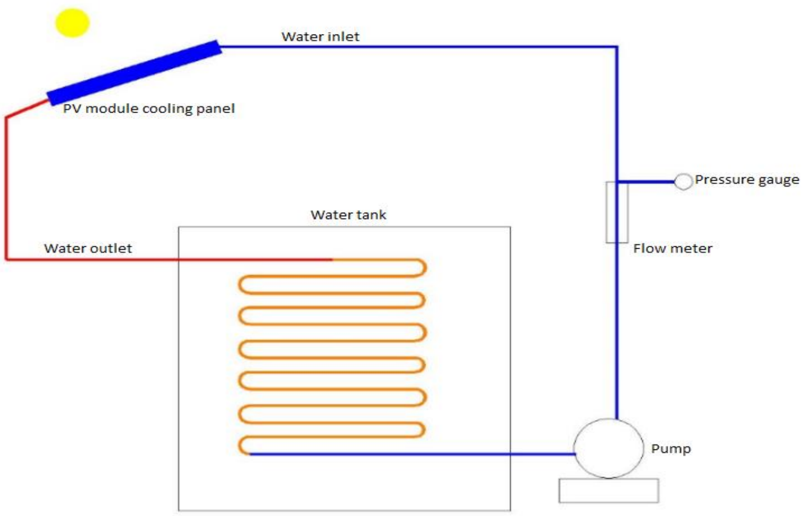

Figure 1: Schematic Diagra of the Experimental Test Setup.

Figure 2: Nano Fluid and Water flowing from bottom of the Solar Photovoltaic Panel.

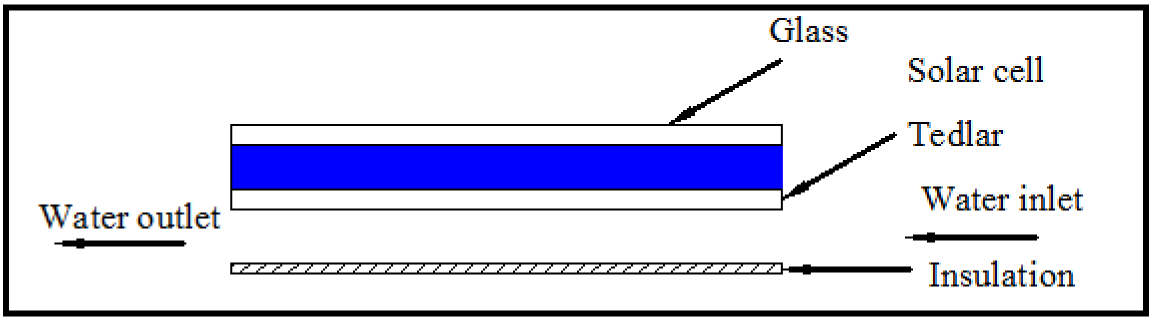

Figure 3: Schematic of the Simulated PVT System.

Table 1: PV Specifications

Solar PV module parameters	Value AM 1.5 spectra STC
Maximum power P_{max}	30W
Open -circuit voltage V_{oc}	22V
Short -circuit current I_{sc}	1.84A
Voltage at P_{max}	18V
Current at P_{max}	1.67A
Operating temperature(°C)	-40 to+85
Dimensions	545x355cm
Radiation G(W/m^2)	1000

3. ELECTRICAL SETUP

In order to measure the module performance, an electrical setup was manufactured. It consists of thermocouple, voltmeter, ammeter and solar intensity meter. Module surface front temperatures are measured by thermocouple at three locations and the average was taken. The instruments used in measurements are shown in Figures (5-9). The accuracy/ sensitivity of the instruments used are given in Table (2). Measurements for PV panel performance evaluation without cooling and with water cooling (at different water volume flow rates) are measured. It can be realized that the generated power by the PV cell decreases by increasing cell temperature. This effect is much more sensible at higher solar radiation which in turn clearly shows the necessity of an appropriate cooling system for PV systems.

Table 2: The Accuracy/Sensitivity of the Instruments

Instrument used	Accuracy/ Sensitivity
Solar power meter	$10W/m^2$
Volte meter and ammeter	1mV
Thermocouple thermometer	$\pm 0.5C^O$

Figure 5: Voltmeter

Figure 6: Solar Intensity Meter.

Figure 7: Flowmeter

Figure 8

Figure 9: Pump

4. RESULTS AND DISCUSSIONS

The results of the out-door experimental tests for best performance of the PV module using Nanofluid (Tio2) at concentrations (0.05 wt.%, and 0.1 wt.%) and water cooling channel thicknesses, 5cm with three volume flow rates 1 L/min, 1.5 L/min and 2 L/min and the duration of each experiment test was seven hours are obtained.

Since insulation is used at the back side, there is no heat exchange there. However, the temperature is within control on the front side with the average temperature near 67oC at the front side. It can be observed that the temperature is particularly higher than at the bottom corners of the panel since water cannot flow and hence remain stationary. The aim to cool from bottom side is to decrease the array surface temperature whereas insulation at the back side prevents heat loss. The results show effective cooling is as the average temperature does not reach very high on the front surface.

The velocity is very low through the cooling channel, however it is higher at entry and exit points to ensure slow

heat exchange between the water and the PV module and to control the temperature. Figure (10) shows the comparison of cell average temperature for PV cells without cooling, cooling with water and Nano fluid for volume flow rate 1L/min during the period of the test. It's clear that, the temperature rises gradually in the three cases. Without cooling, the cell average temperature reached 67oC which was the highest value, cooling with water and Nano fluid at concentrations (0.05 wt.% and 0.1 wt.%)(46.8 ºC, 43.8 ºC and 42.6ºC) respectively at eleven o'clock. This result indicates that heat is not getting wasted from the bottom because of insulating layer at the bottom. This also ensures heat transfer direction from the bottom up across PV panel layers as of the time progresses. It is explicit from Figures (10,11 and 12) that there is a significant decline in PV panel temperature as a result of cooling from top surface and resulted in the reduction of the cell temperature up to (42.6 ºC, 45.1 ºC and 42.8 ºC) respectively at eleven o'clock. The percentage reduction in average cells temperatures were (30%, 31% and 32%) for volume flow rate 1 L/min, 1.5 2L/min as shown in Figure (10,11and12) respectively. It is obvious from the figures that the best results for cooling of PV module was with cooling channel thickness 5 cm, flow rate of 2 L/min and Tio2 at concentrations (0.1 wt.%).

The percentage of the increase of the generated power and temperature, which is a dimensionless parameter, was calculated as follows: **I. AL Masalha [25]**

$$\%T_{\max,\,increase} = \frac{T_{withoutcoding} - T_{cooling}}{T_{withoutcoding}} * 100\% \qquad (1)$$

$$\%P_{\max,\,increase} = \frac{P_{cooling-}P_{withoutcoding}}{P_{withoutcoding}} * 100\% \qquad (2)$$

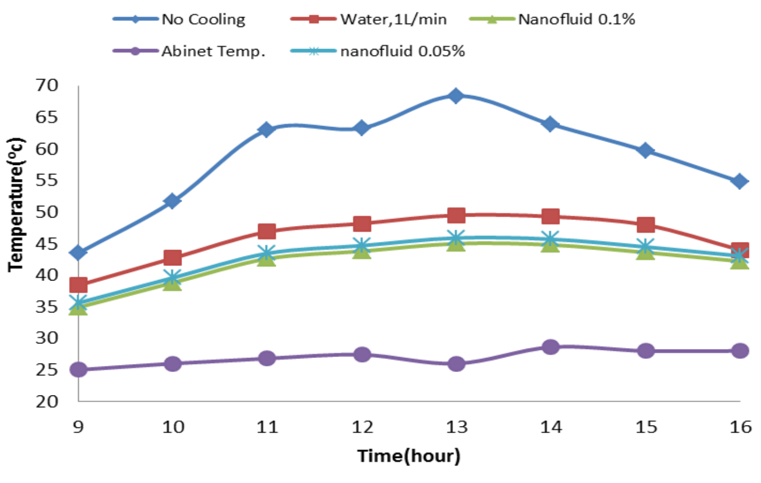

Figure 5: Comparison of an Average Temperature with and without Cooling for Volume Flow Rate= 1L/min.

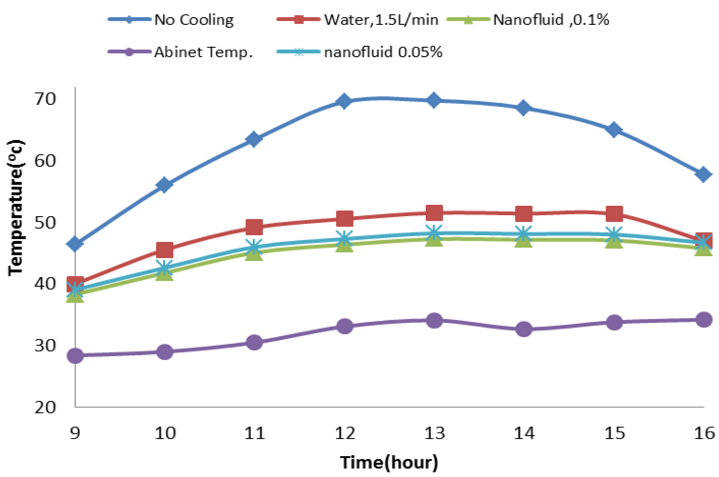

Figure 6: Comparison of an Average Temperature with and without Cooling for Volume Flow Rate= 1.5 L/min.

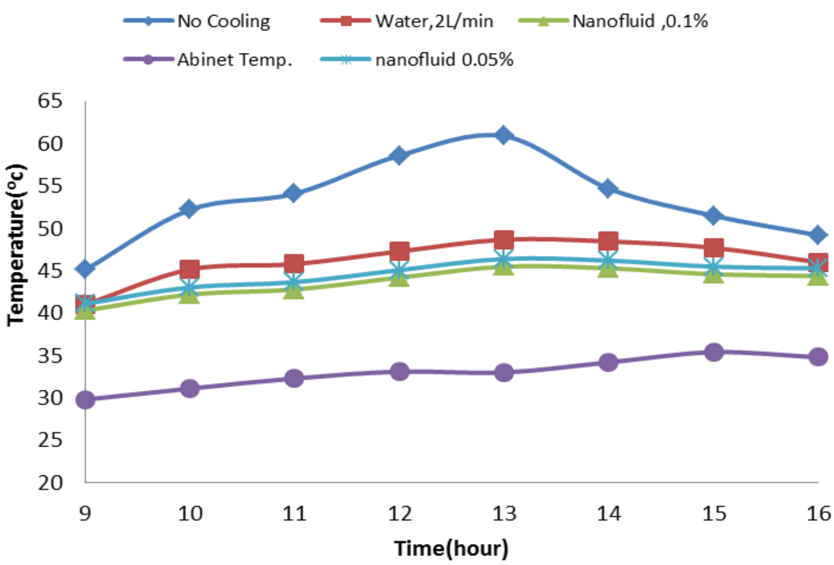

Figure 7: Comparison of an Average Temperature with and without Cooling for Volume Flow Rate= 2L/min.

The power and efficiency with and without cooling were worked out as a case to understand the effect of cooling on the power and overall efficiency. It has been observed that the power and efficiency were improved. This enhancement in thermal power of PV module for the best case is shown in Figure (15). The power of the module without cooling reached the lowest value of (20.8 W) at eleven o'clock, while with water cooling it reached (21.4) and with Nano fluid reached (22.4W) with percentage increase of (2.3%) and (7.6%). The efficiency of the PV module without cooling was (14%), while with cooling it reached (14.8%) and while for case of Nano fluid cooling it reached up to (15.5%).

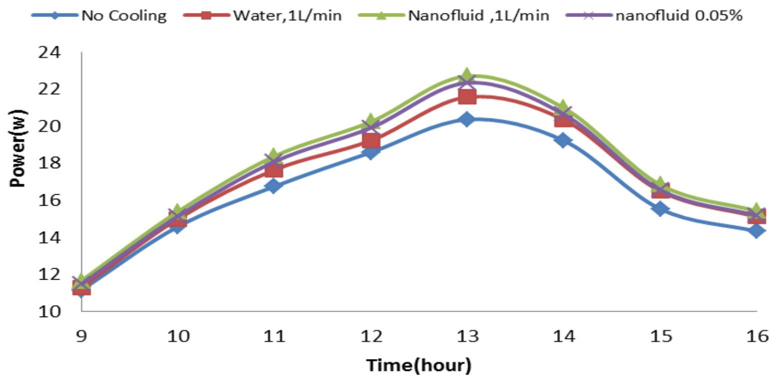

Figure 8: Comparison of a Power with and without Cooling for Volume Flow Rate= 1L/min.

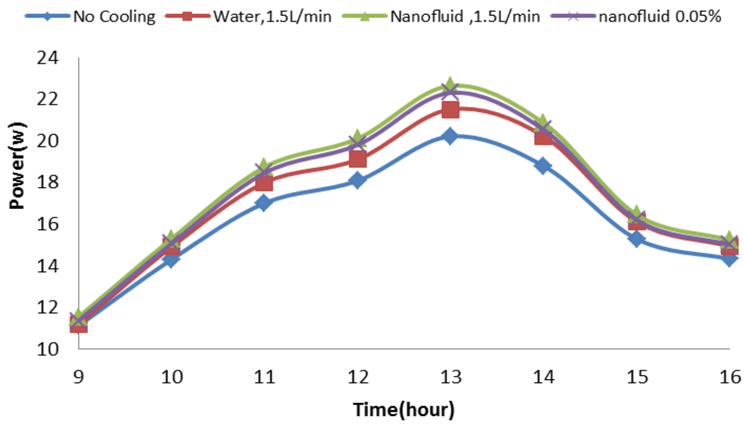

Figure 9: Comparison of a Power with and without Cooling for Volume Flow Rate= 1.5L. min.

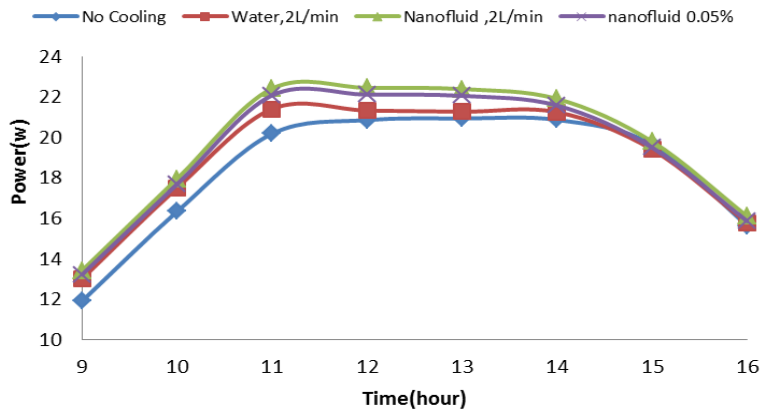

Figure 10: Comparison of a Power with and without Cooling for Volume Flow Rate= 2L/min.

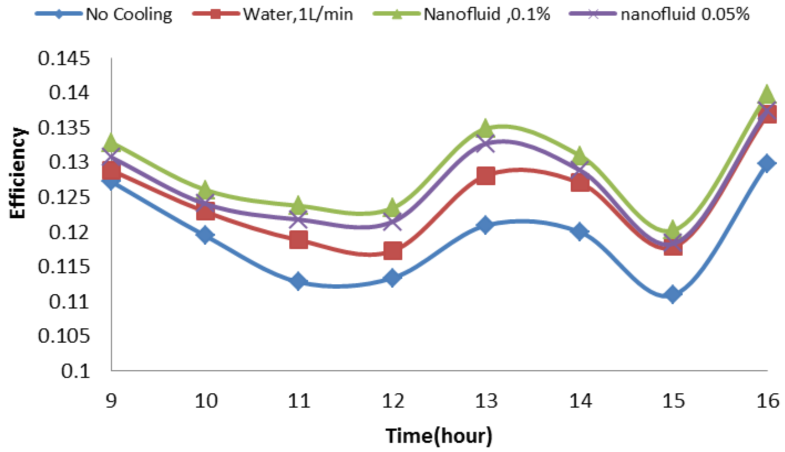

Figure 11: Comparison of Efficiency with and without Cooling for Volume Flow Rate= 1L/min.

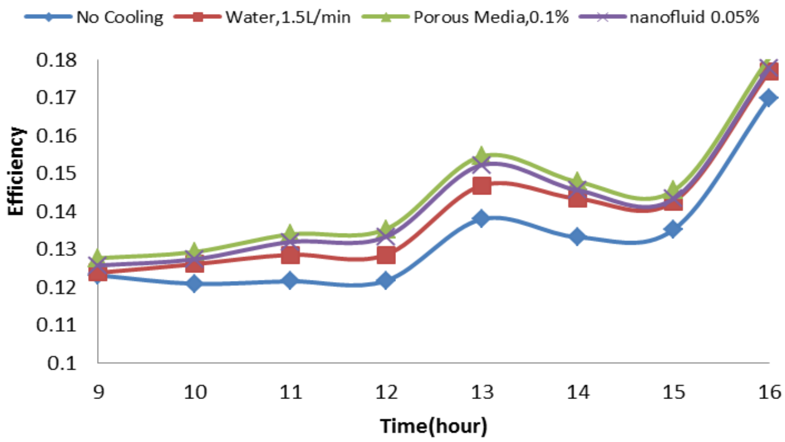

Figure 12: Comparison of an Efficiency with and without Cooling for Volume Flow Rate= 1.5L/min.

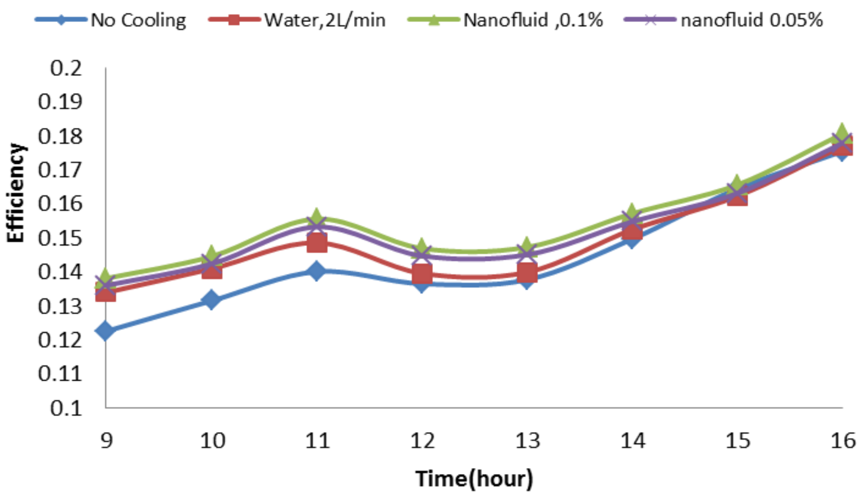

Figure 13: Comparison of Efficiency with and without Cooling for Volume Flow Rate= 2L/min.

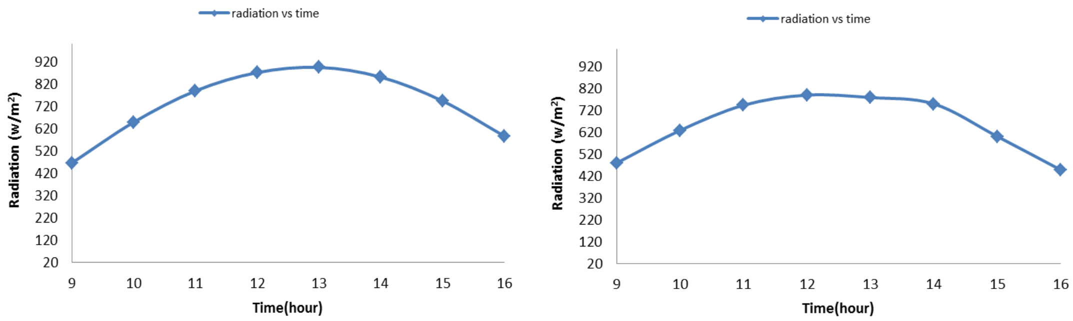

Figure 14: Distribution of Measurements of Solar Irradiance for Experiments (22/06/2018) and 23/06/2018.

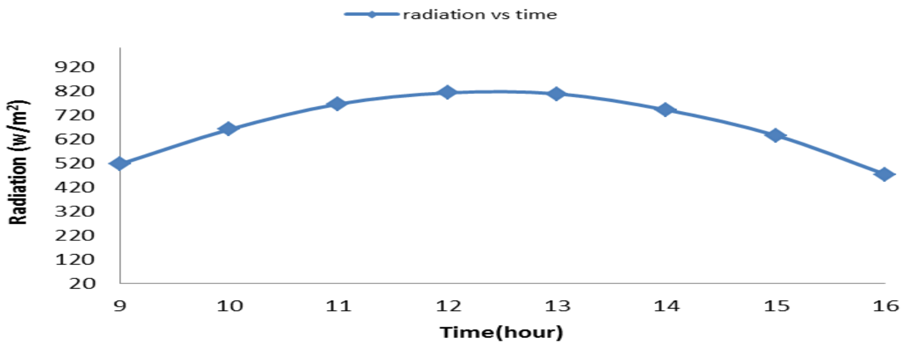

Figure 15: Distribution of Measurements of Solar Irradiance for Experiments (24/06/2018).

5. CONCLUSIONS

Experimental of a PV-Nanofluid cooling hybrid framework is examined in regards to its thermal and electrical execution.

Experimental investigations of a PV module performance under cooling channel thicknesses 5cm and different volume flow rates are performed. Based on the results found, the following conclusions may be drawn:

- The best performance of the PV module cooling with Nanofluid (TiO_2) at concentrations (0.1 wt. %) is obtained with volume flow rate of 2 L/min.
- Without cooling, the operating cell temperature reached the highest value of about 63^{o}C. While, using water cooling, the reduction in an average temperature was (32%).
- The corresponding efficiency of the PV module without cooling was (14 %), while for case of Nano fluid cooling it reached up to (15.5%).

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